1. Chapter One, Introduction

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1.1. Introduction to the C-AD SAD

The Collider-Accelerator Department (C-AD) Safety Analysis Document (SAD) presents a basic statement of the facility's missions, the protections that are afforded the public and worker's health and safety, and the protection of the environment. An overview of the results and conclusions of the safety analysis are contained within Chapter 2. Comprehensiveness of the safety analysis and appropriateness of the Accelerator Safety Envelope are also addressed in Chapter 2. The environment within which the facility was constructed, those facility characteristics that are safety-significant and the methods used to operate the accelerators within the Collider-Accelerator Department are presented in Chapter 3. Chapter 4 documents the analysis, including the methodology, used for identification and mitigation of potential hazards. Chapter 5 is the policy for the engineered and administrative bounding conditions within which the Collider-Accelerator Department operates the accelerators; that is, the policy for an Accelerator Safety Envelope. Detailed limits are prescribed in the Accelerator Safety Envelope (ASE), which is a separate document that relates to the SAD. That is, the SAD is the foundation for the ASE. Chapter 6 describes the quality assurance program at the Collider-Accelerator Department, focusing upon activities that impact protection of the worker, the public or the environment. A description of structural and internal features that facilitate decommissioning of the accelerators and support facilities within the Collider-Accelerator Department is presented in Chapter 7. In Chapter 7, waste management of radiological and hazardous material generation from a future decommissioning operation is discussed within the context of present-day Department of Energy requirements. The final chapter, Chapter 8, includes a summary of acronyms, abbreviations and references with hyperlinks used throughout the document.

Information in this document is available on the web at http://www.rhichome.bnl.gov/AGS/Accel/SND/c-a_sad_and_ase.htm. Related documents such as previously approved Safety Assessment Documents, maps, references and other safety related documents have been archived on the web at http://www.rhichome.bnl.gov/AGS/Accel/SND/chronology_of_eshq_at_c-ad.htm.

1.2. C-AD Mission

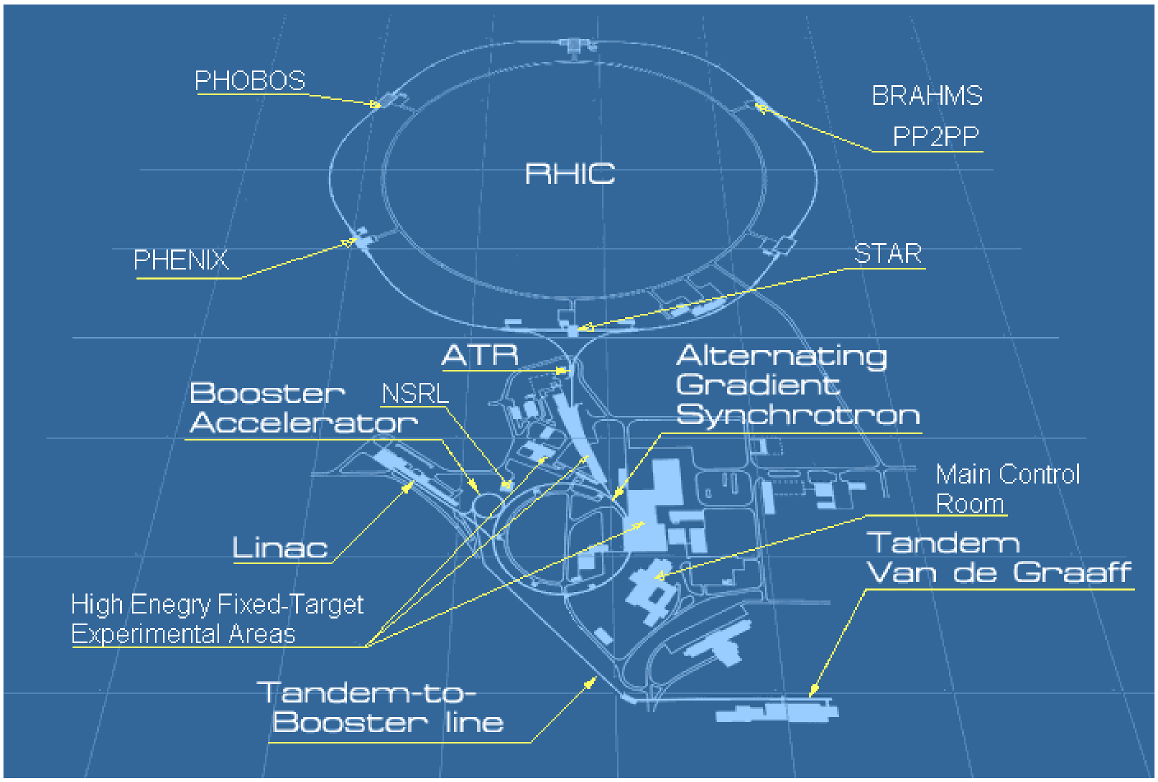
Brookhaven National Laboratory (BNL) is a government-owned, contractor-operated nuclear physics facility that was founded in 1947 to provide a center for nuclear science in the northeastern United States. During the period 1947 to the present, BNL's accelerator facilities have evolved in terms of accelerator type, particle type, target type, particle energy, particle intensity, administering organizations and missions. Today's Collider-Accelerator Department oversees 7 accelerators and 10 experimental areas and is the successor organization to the Accelerator Department, Booster Project, RHIC Project, BAF Project and AGS Department. The current missions of the Collider-Accelerator Department are:

- to develop, improve and operate the suite of particle / heavy ion accelerators used to carry out the program of accelerator-based experiments at BNL
- to support the experimental program including design, construction and operation of the beam transports to the experiments plus support of detector and research needs of the experiments
- to design and construct new accelerator facilities in support of the BNL and national missions
- to achieve excellence in environmental responsibility and safety in all C-A Department operations

The C-A Department supports an international user community of over 2000 scientists. The department performs all these functions in an environmentally responsible and safe manner under a rigorous conduct of operations approach.

Figure 1.2.a illustrates the various accelerators that make up the complex and shows the facilities that connect them.

Figure 1.2.a Accelerators and the Collider within C-AD Site



The Tandem Van de Graaff (TVDG) facility, commissioned in 1970, houses two TVDG accelerators that provide low-energy heavy-ion beams for injection to the Booster through a beam transfer line, or they provide light and heavy ion beams for technological and industrial applications within local target halls. The TVDG accelerators use static electricity to accelerate atoms after removing some of their negatively charged electrons, which are in a cloud around the nucleus. An atom with a charge imbalance is called an ion. A partial lack of electrons gives each ion a strong positive charge. Two separate Tandems give billions of these ions a boost of energy, sending them on their way towards the Booster accelerator or directly to experiments in the TVDG target rooms.

Completed in 1991, the Tandem-to-Booster line (TtB) extends the beam line from the TVDG to the Booster accelerator. The TtB extended an existing beam line known as the Heavy Ion Transfer Line (HITL) that directly injected heavy ions from TVDG into Alternating Gradient Synchrotron (AGS) accelerator from 1986 to 1991. In the current mode of operations, bunches of ions leave the TVDG at about 5% the speed of light and enter the TtB. They travel unimpeded through a vacuum pipe. Magnets are used along the TtB to steer the beam bunches into the Booster. The ions are further stripped of outer shell electrons by passing through a metallic foil prior to entering the Booster.

In addition to heavy ions, some experiments require protons. For these experiments, negatively charged hydrogen ions are supplied to the Booster from a 200 million-electron-volt (MeV) Linac, which was completed in 1970. Negatively charged hydrogen ions from the Linac are transferred to the Booster and stripped of their two electrons to become bare protons as they enter Booster. Linac also supplies protons to the Brookhaven Linac Isotope Producer (BLIP) in Building 931. The BLIP facility is used to make radio-chemicals that are transported to Medical Department laboratories and manufactured into radiopharmaceuticals. Prior to 1991, protons from Linac were injected into AGS directly via the High Energy Beam Transport (HEBT) tunnel. The HEBT tunnel continues to exist and is seen in Figure 1.2.a; however, the steering magnets that direct the beam to the AGS have been removed, and the HEBT to AGS interface has been appropriately shielded.

The Booster synchrotron was commissioned in 1991. The Booster is a powerful compact circular accelerator that provides positively charged ions more energy by having them "surf ride" on the downhill slope of radio-frequency electromagnetic waves. The ions are propelled forward at higher and higher speeds, getting closer and closer to the speed of light. The Booster feeds energetic beams into another accelerator, the Alternating Gradient Synchrotron (AGS), or into an experimental area, the NASA Space Radiation Laboratory (NSRL). Typical energies of particles at Booster extraction are 1.5 GeV for protons, 0.1 to 1.1 GeV per nucleon for Fe ions and up to 0.35 GeV per nucleon for Au ions.

Commissioned in 2003, the NSRL is a national facility for research in the diverse field of biological effects of high-proton number, high-energy particles. The NSRL's design is broad and diverse to allow pursuits of a variety of aspects in the field of biological effects. At the same time, the facility is capable of answering the most basic question in this field, which is quantifying the risk to humans in different shielding environments from exposure to ionizing particles in galactic cosmic rays. NSRL is not an accelerator, rather it is a beam line and target hall that extends from the Booster and it includes experimental support facilities.

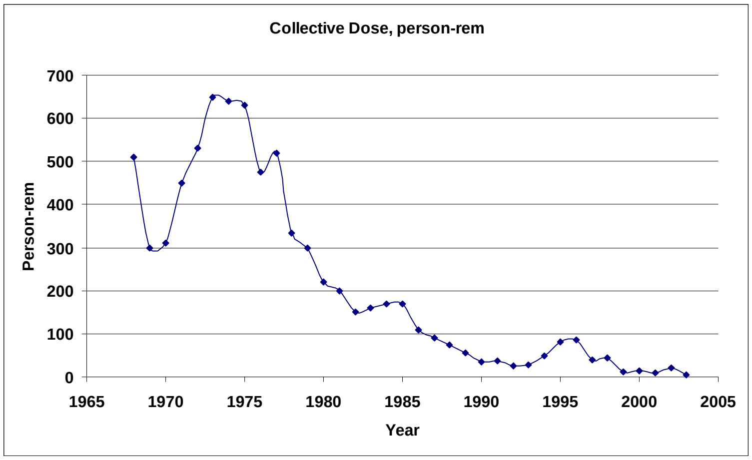
The AGS was commissioned in 1960. The AGS is the heart of the accelerator complex and more information about its capabilities is presented in the sections that follow.

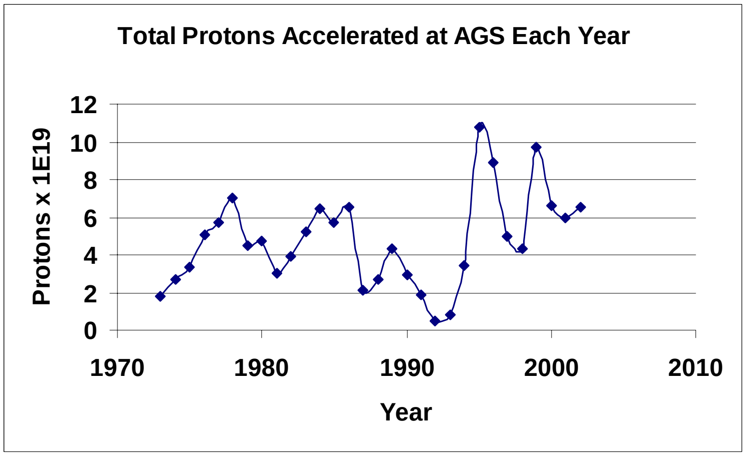
As ions enter the AGS from the Booster, they travel at about 37% the speed of light and they are further stripped of electrons making them more positively charged. As they whirl around the AGS, the ions get even more energy until they are traveling at 99.7% the speed of light.

In 1960, the AGS was developed and first operated at its full energy of 33 GeV for protons. Originally developed as a proton accelerator, the AGS was adapted to accelerate heavy ions in addition to protons in 1986. In 1986, the AGS accelerated protons at an intensity of 15 teraprotons (TP) per AGS pulse to energies of 33 GeV. The injection intensity available to the AGS since 1970 from the Linac injection source has been 150 TP per AGS pulse. AGS pulses are normally repeated every 1.8 to 5 seconds. Until 1991, the AGS lacked the ability to capture and accelerate this intensity of protons from Linac since beam loss, radiation burdens to personnel, and equipment damage prevented operation at this intensity. In 1991, the Booster was constructed to provide additional intensity capabilities to the AGS and allow the AGS to achieve energies for heavy ions that would permit extraction at high enough energy and intensity to inject measurable amounts of beam into the Relativistic Heavy Ion Collider (RHIC). Since installation of the Booster, accelerated protons in AGS have achieved a beam intensity of 80 TP per pulse at maximum energy. In the near future, the AGS will be able to routinely accelerate 100 TP per pulse.

Due to continuous improvements in beam transport and control, routine operation and maintenance actions associated with the accelerator facilities continues to result in a reduction in radiation exposures to workers despite the increased intensity. Figure 1.2.b shows this continuous dose reduction graphically during a period of time when the AGS output increased significantly.

Figure 1.2.b Collective Dose Equivalent Experience and Annual Proton History





1.2.1. AGS Slow Extraction (SEB)

The process of creating a slow spill of about 1.5 seconds involves slowly moving the beam in the AGS. Back-leg winding bumps centered on H20 and F7 hold the beam near the H20 electrostatic septum and the F5 septum magnet, allowing it to be slowly peeled out of the accelerator into the Switchyard, where the beam is split into parts while being transported to the target stations. Prior to moving the circulating beam in the AGS Ring, the beam is de-bunched and given an overall larger momentum spread.

1.2.2. AGS Fast Extraction (FEB)

The FEB extraction system performs multiple single-bunch extraction of either a heavy-ion beam or a polarized-proton beam for RHIC through the AGS-to-RHIC transfer line or a high intensity proton beam to the V-target at a rate of 30 hertz up to 8 times per AGS cycle. For experiments off the V target, the FEB extracts a 50-nanosecond bunched proton beam up to full energy and intensity and performs single-bunch multiple-extraction at 33.3 ms intervals up to 12 times per AGS cycle. An AGS cycle typically repeats every 2 to 3 seconds. The remaining bunches at the end of a cycle, if any, have to be de-bunched and be slowly extracted into the SEB channel. As an injector for RHIC, the AGS may accelerate a variable number of bunches per cycle, e.g., three bunches per cycle and transfer individual bunches one by one into the waiting rf buckets in RHIC through the AGS to RHIC transfer line. Each RHIC ring is filled with up to 120 bunches one after another in a few minutes approximately every 5 hours for heavy ions and every 10 hours for protons.

1.2.3. AGS Switchyard

Once the beam is extracted to the AGS Switchyard, it is split into at most 4 beams, which get transported to the four target stations: A, B, C, and D. Beam is bent away from the AGS Ring by about 1.5 milli-radians with the F5 Septum and about 20 milli-radians with the F10 septum. About 12.5 meters from F10, the beam is bent back towards the AGS about 10 milli-radians by the CD1 magnet to provide more clearance between D line and the target building wall (Building 912). Immediately after CD1 there are four quadrupoles that match the external beam emittance to the requirements of the splitting and transport magnets. Basically a parallel beam is created with low dispersion and constant beam size so that it can travel through splitters and Lambertson pitching magnets with minimal beam loss. Since a particle spill from AGS has a higher momentum at the beginning and a lower momentum at the end, about a 1 % difference, the larger bending magnets in the Switchyard have their current ramped down during the spill.

The beam is split into four pieces by 3 electrostatic wire splitters, which run at about 60 to 80 kV and bend the beams by about +/- 0.3 milli-radians each. For each splitter there is a corresponding Lambertson pitching magnet, whose septum is lined up with the shadow created by the wire splitter. These are thin Lambertson magnets, about 60 mils thick, that each bends the beam about 6 to 8 milli-radians vertically.

The Switchyard, which was commissioned in 1979, may receive fast extracted beam using the H-10 system or receive slow extracted beam using the F-10 system. In both cases, beam pulses may repeat as fast as every 1.8 seconds. In the past, as many as 15 secondary beam lines may be arrayed from the four primary fixed targets at A, B, C and D in Building 912. Secondary beams of rare particles arise from striking primary targets with extracted beams. These secondary beams are used in experiments to study the fundamental properties of hadrons and leptons.

1.2.4. AGS Fast Extraction Beam Lines

The fast extraction beam lines consist of the V line, which was commissioned in 1995, the U line which was commissioned in 1971, and the W line, which was commissioned in 1996.

The AGS extracts full intensity fast bunches via the H-10 extraction system into the V beam line and onto a single fixed target, the V target. Extremely short-lived secondary particles, pions and muons, are emitted from the V target and stored in a superconducting ring magnet in Building 919. Experiments in Building 919 are aimed at studying the fundamental properties of leptons.

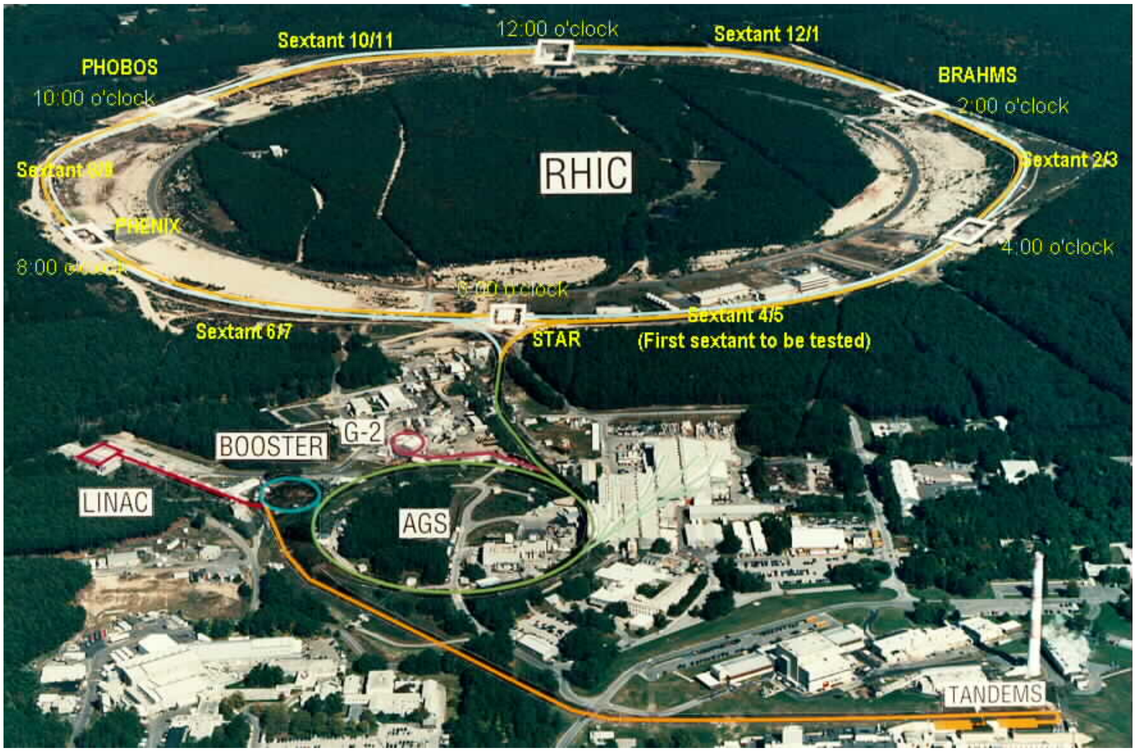
The AGS also extracts low intensity fast bunches via the H-10 extraction system into the U beam line and onto many types of fixed targets in the U line. Most targets receive only a few pulses of beam at reduced intensity. For example, this experimental area is currently used for an applied physics program known as proton radiography.

1.2.5. X and Y Lines and RHIC

The W line is used to transfer beams to the X and Y lines that lead into the RHIC. The AGS-to-RHIC (AtR) transfer line, which was commissioned in 1996, contains the U, V and W beam lines. When the proton beam or heavy ion beam is traveling at top speed in the AGS, it may be steered down the W line toward RHIC. At the end of this line, there is a “fork in the road,” where a switching magnet sends the ion bunches down one of two beam lines. Bunches are directed either left to travel clockwise in the RHIC blue ring or right to travel counter-clockwise in the RHIC yellow ring. The RHIC rings were commissioned in 1999. In RHIC, counter-rotating beams are accelerated up to 250 GeV for protons and 100 GeV per nucleon or heavy ions. The two counter rotating beams circulate in RHIC where they are collided into one another at as many as six interaction regions. Currently, four interaction regions are in use by the BRAHMS (Broad Range Hadron Magnetic Spectrometer), PHOBOS (not an acronym), STAR (Solenoid Tracker at RHIC), and PHENIX (Pioneering High Energy Nuclear Interaction eXperiment). See Figure 1.2.4.

Additionally, there is a polarized-hydrogen-gas target (JET) in RHIC and it is used for elastic scattering measurements when polarized proton beams are circulating. The JET target is located at the 12 o’clock intersection point and the two opposing beams in RHIC are separated by ~10 mm instead of colliding. Only one beam at a time interacts with the JET target.

Figure 1.2.5 Accelerators and the Collider Showing the Yellow and Blue Rings



1.3. Basic Safety, Health and Environmental Protections at C-AD

The C-AD accelerators are classified as low-hazard accelerator facilities subject to the requirements of the DOE Accelerator Safety Order, DOE O 420.2A or its successors. These requirements are promulgated in BNL's Accelerator Safety Subject Area. A low-hazard facility is defined to be one with potential for no more than minor on-site and negligible off-site impacts to people and the environment. The possibility of any off-site impacts or major on-site impacts is highly unlikely due to the physical aspects of the C-AD accelerators and collider rings whereby:

- they are dependant upon external energy sources; that is, electric power, that can be easily terminated
- the primary hazard is prompt ionizing radiation that is limited to regions where the beam is maintained and is in existence only when a beam is present

The Collider-Accelerator Department has embraced DOE's Integrated Safety Management System as a basic protection for workers and experimenters. The Laboratory's Standards Based Management System (SBMS) promulgates the requirements of Integrated Safety Management through Subject Areas such as Accelerator Safety, Working with Chemicals, Critiques, Engineering Design, Hazard Analyses, Hazardous Waste Management, Lessons Learned, Work Planning and Control, and Stop Work.

To provide excellent science and advanced technology in a safe and environmentally responsible manner the Collider-Accelerator has, over the past decade, continuously reviewed the hazards of its operations in an effort to identify and accomplish injury and illness prevention opportunities. This effort has resulted in a further formalization of DOE's Integrated Safety Management System under the requirements of the OHSAS 18001 Standard, Occupational Safety and Health Management Systems - Specifications.

The following hazards are significant to the Collider Accelerator Department activities:

- ionizing radiation
- hazardous or toxic materials
- radioactive materials
- electrical energy
- explosive gases and liquids
- oxygen deficiency
- kinetic energy
- potential energy
- thermal energy
- cryogenic temperatures

The C-A Department is committed to identifying hazards during the planning phase of its operations. This is accomplished through implementation of the following operational procedures: C-A-OPM 2.28, C-A Procedure for Enhanced Work Planning; C-A-OPM 2.29, C-A Procedure for Enhanced Work Planning for Experimenters; C-A-OPM 9.1.12, Review of C-A Shielding Design; C-A-OPM 9.1.15, Guideline for Review Criteria for C-A Experiments; C-A-OPM 9.2.1, Reviewing Conventional Safety Aspects of an Experiment; and C-A-OPM 9.3.1, Reviewing Conventional Safety Aspects of an

Accelerator System. As determined by the C-A OSH Management Representative, processes that introduce new hazards that are identified through planning and reviews are also reviewed by members of the Worker Occupational Safety and Health (WOSH) Committee in order to obtain worker input. The AGS Low Hazard Class Determination and the Workplace Hazard Analyses and Risk Assessments serve as the technical baseline through which hazards have been identified. Workplace Hazard Analyses and Risk Assessments are reviewed and updated annually or as required by significant process change.

In order to guide operations and maintenance of the accelerators, beam lines and associated systems at the Department level, the SBMS Subject Areas are used to:

- define the scope of work in a Work Permit or establish the applicability
- identify the hazards via the Work Permit process and perform a pre-job walk down
- use the Work Permit processes to establish hazard controls and required training
- provide the pre-job briefing and perform the work according to plan/permit
- use the Work Permit feedback process to identify ways to improve next time

In order to guide Users during experiment design and operations, the SBMS Subject Areas are used to:

- determine the concept and scope of the experiment; assess for special requirements, review hazards and safety concerns
- develop an experimental plan and identify controls
- set up an experiment and obtain Experimental Safety Review Committee concurrence
- approve start-up and perform the experiment according to plan
- determine ways to improve next time

Workers and experimenters at the C-AD work in or near radiological areas. The rules in 10CFR835 establish radiation protection standards, limits and program requirements for protecting individuals from ionizing radiation resulting from the conduct of DOE activities. These requirements are promulgated in BNL's RadCon Manual. Basic radiation protection systems and programs include:

- access control system
- fixed-location and interlocking area-radiation monitors
- shielding, posting and fencing
- training and qualifications for radiation workers, experimenters and visitors
- personnel monitoring
- radiation work permits
- ALARA reviews of jobs and experiments when needed
- daily radiation surveys using portable radiation monitors
- control of radioactive materials and sources

Basic fire protection includes compliance with DOE fire protection guidelines as well as NFPA's guidelines. The fire protection systems are integrated with the site-wide system. They include automatic fire detection and suppression systems that may consist of automatic Inergen gas suppression, fire-wire detection, smoke detection, fire-rated walls used to separate fire protection zones, automatic wet-pipe and dry-pipe fire suppression, and rapid response capability coverage by the BNL Fire Department. The means of egress for occupancies is in accordance with NFPA 101.

The environmental policy as set forth by Brookhaven National Laboratory in the Environmental Stewardship Policy is the foundation on which the C-A Department manages significant environmental aspects and impacts. Based on the aspect identification and analysis process in the Subject Area, Identification of Significant Environmental Aspects and Impacts, the following aspects are significant to the Collider Accelerator Department activities:

- regulated industrial waste
- hazardous waste
- radioactive waste
- mixed waste
- atmospheric discharge
- liquid effluents
- storage and use of chemicals or radioactive material
- soil activation
- PCBs
- water consumption
- power consumption
- environmental noise

The formal management program for these aspects is called the C-A Environmental Management System (EMS), which complies with ISO 14001. Basic environmental protections that address significant environmental aspects identified by the Environmental Management System include:

- concrete and iron shields to reduce soil activation and sky shine radiation to as low as reasonably achievable
- formal design reviews for modifications

- drawing configuration control
- domestic water supply equipped with back-flow prevention to isolate domestic water supply systems
- systems to hold-up spilled liquids
- systems for ventilation
- waste-handling training and qualifications
- segregation and lock-down of ordinary waste streams, hazardous waste streams and radioactive waste streams
- isolation of storm-sewer drain-lines near the accelerators and experimental areas
- water-impermeable barriers to prevent rainwater from leaching radioactivity from activated soil locations
- Suffolk County Article 12 Code compliance in the design of cooling water systems and piping that contain tritium above the EPA Drinking Water Standard
- compliance with 40CFR61, Subpart H for airborne emissions
- alarms on water systems to detect leaks and alert operations personnel
- isolated closed cooling-water systems to reduce the volume of tritiated water
- process evaluations that describe processes and waste streams in detail, regulatory requirements, waste minimization activities, pollution prevention activities and opportunities for improvement

Management Reviews are used at C-AD to evaluate the overall strategy of the environmental, occupational safety and health (OSH), and self-assessment management systems to determine whether they meet planned performance objectives. The Management Reviews evaluate each management system's ability to meet the overall needs of C-AD and its stakeholders, including its workers and the regulatory authorities. The Review evaluates the need for changes to each management system, including OSH and environmental policy and objectives, and identifies what action is necessary to remedy any deficiencies in a timely manner, including adaptations of other aspects of C-AD's management structure and performance measurement.

The annual Management Review of these ESH management systems provides the feedback direction, including the determination of priorities, for meaningful planning and continual improvement. Senior managers evaluate progress towards C-AD's objectives and corrective action activities and evaluate the effectiveness of follow-up actions from earlier Management Reviews. The frequency and scope of periodic reviews of these management systems is defined according to C-AD's needs and conditions. The Management Review is normally performed annually and normally considers:

- the results of environmental spills, airborne releases, work-related injuries, ill health, diseases and incident investigations
- performance monitoring and measurement and audit activities
- additional internal and external inputs as well as changes, including organizational changes, that could affect each management system

The findings of the Management Review are recorded, posted on the web and formally communicated to the persons responsible for the relevant elements of the management systems so that they may take appropriate action. The results are also communicated to workers and other stakeholders.